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SCADA simulation of a distributed generation system with storage technologies

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Abstract

This paper describes the simulation of a distributed generation system with storage technologies. The simulation is performed using a SCADA software for a distributed generation system, considering the generation cost, the load and the availability of the system's generating units. Also, a storage unit is added to the system. An overview of the storage technologies is also presented.
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1. Introduction

Power systems face new challenges, such as increasing grid integration from distributed generators (DGs), especially from wind sources. The DG sources are intermittent, so the power provided at any time of the day will fluctuate depending on the availability of their primary energy source. This leads to stability, reliability and quality problems of the grid. Energy storage technologies can manage these fluctuations and thus help reduce these problems.

Therefore storage systems with sufficient energy reserve, high power capability and very fast response time are required.

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The simulations regarding the distributed generation systems or power systems do not contain a storage unit in their analysis.

The system's generating units cover demand in order of their generating cost coefficient, with the observation that if the distributed energy sources are on-grid, they have priority access to the system. This is because the power provided by the distributed generator is variable in time due to the availability of their primary source.

When the demand is higher than the generation output or the distributed generators are off-grid, the storage unit will be used to cover the remaining power.

2. Overview of storage technologies

The most important storage technologies are:

- electromagnetic (supercapacitors and superconducting magnetic energy storage);
- electrochemical (all types of batteries and hydrogen based energy storage);
- mechanical (pumped hydro storage, compressed air energy storage and flywheels).

Based on their energy storage capacity, energy storages can be categorized as short-term and long-term energy storages. Short-term storage systems include the supercapacitor energy storage, flywheel energy storage and superconducting magnetic energy storage. The long-term storage systems could be subdivided into pumped hydroelectric energy storage, compressed air energy storage, battery energy storage and hydrogen energy storage.[1]

An overview of these storage systems is presented further.

2.1. Battery storage

Storage batteries are rechargeable electrochemical systems used to store energy. They deliver, in the form of electric energy, the chemical energy generated by electrochemical reactions. These reactions are set in train inside a basic cell, between two electrodes plunged into an electrolyte, when a load is connected to the cell's terminals. The reaction involves the transfer of electrons from one electrode to the other through an external electric circuit/load. There are three main types of storage batteries: lead–acid batteries, nickel based batteries and lithium based batteries.[8]

Battery storage systems provide spinning reserve, area frequency and voltage control. But the high initial cost of battery storage systems and low cycle life is a real disadvantage.

2.2. Flywheels

A flywheel is a mass rotating about an axis, which can store energy mechanically in the form of kinetic energy. Energy is required to accelerate the flywheel so it is rotating. This is usually achieved by an electric motor when being used in an electrical system. Once it is rotating, it is in effect a mechanical battery that has a certain amount of energy that can be stored depending on its rotational velocity and its moment of inertia. The faster a flywheel rotates the more energy it stores. This stored energy can be retrieved by slowing down the flywheel via a decelerating torque and returning the kinetic energy to the electrical motor, which is used as a generator.[8]

The advantages are: long life, high energy density, low maintenance structure.

2.3. Compressed air energy storage system (CAES)

This technology uses the potential energy of compressed air to drive turbines. Air is pumped into a suitable underground cavern (e.g., salt cavern, depleted gas field). To extract the stored energy, compressed air is heated, expanded, and directed through a high-pressure turbine that captures some of the energy in the compressed air. The air is then mixed with fuel and combusted, with the exhaust expanded through a low-pressure gas turbine. The turbines are connected to an electrical generator.[14]

The structure of CAES is similar to that water pumped storage system, with the difference that air, not water, is used as storage. During peak demand, electricity is produced by releasing the air from the cavern.

2.4. Pumped storage hydroelectricity

The operation principle of a pumped storage hydroelectric power plant involves changing the potential energy of the water into its kinetic energy and then further into electricity.

A pumped storage scheme consists of an upper and a lower reservoir and reversible turbine/generators, which can be used as both turbines and pumps. The upper reservoir typically has sufficient storage for 4–6 hours of full-load generation. The operation principle is as follows. At times of low electricity demand, excess generation capacity is used to pump water into the upper reservoir. When there is higher demand, water is released back into the lower reservoir through the turbine, generating electricity.[8,15]

The cost of energy storage can be lower in pumped hydroelectric systems than other systems.

2.5. Superconducting magnet energy storage (SMES)

The principle of SMSE employs the storage of energy in the magnetic field around the coil carrying direct current.

SMES is achieved by inducing DC current into a coil made of superconducting cables of nearly zero resistance, generally made of niobium-titane (NbTi) filaments that operate at very low temperature (-270 °C). The current increases when charging and decreases during discharge and has to be converted for AC or DC voltage applications.[9] SMSE is perfect for situations where great power is needed for a short period time, as the basic disadvantages of SMES are its low capacity and short storage period.

2.6. Hydrogen storage

Hydrogen is one of the promising alternatives that can be used as an energy carrier. The universality of hydrogen implies that it can replace other fuels for stationary generating units for power generation in various industries.[1]

Essential elements of a hydrogen energy storage system comprise an electrolyzer unit which converts electrical energy input into hydrogen by decomposing water molecules, the hydrogen storage system itself and a hydrogen energy conversion system which converts the stored chemical energy in the hydrogen back to electrical energy.[1]

Storing energy in the form of hydrogen has the following advantages: easy energy transmission, unlimited storage period and easy installation scaling.

2.7. Supercapacitors

It is a new energy storage device and its capacity of discharge current is very much higher than a traditional one. They are used mostly in as storage units in power systems and vehicles.

Supercapacitors (or ultracapacitors) are very high surface areas activated capacitors that use a molecule-thin layer of electrolyte as the dielectric to separate charge. The supercapacitor resembles a regular capacitor except that it offers very high capacitance in a small package. Supercapacitors rely on the separation of charge at an electric interface that is measured in fractions of a nanometer. [8,9]

Table 1. Comparison of storage technologies.

Storage system	Capacity	Power	Start-up time	Storing time
Batteries	kWh to MWh	kW to MW	Milliseconds	Days
Flywheels	kWh	100 kW	Seconds	Hours
CAES	100 MWh	100 MW	12 min	Months
Pumped hydro	1000 MWh	10-1000 MW	2-5 min	Months
SMES	1 MW	kW to MW	Seconds	Minutes
Hydrogen	10 MW	kW to MW	Seconds	Months
Supercapacitors	10000 F	kW to MW	Milliseconds	Minutes

3. Distributed generation system data

The simulation is performed for the IEEE 30 bus test system, in which three DG sources were added (a 4 MW hydro generator HYDRO, a 0.3 MW photovoltaic plant PV and a 3 MW wind turbine WT).

The loads data are presented in table 2, the generators data are presented in table 3, and the cost coefficients for the generating units are presented in table 4. The data for the loads, generators, and cost coefficients are formulated in [6, 16].

Table 2. Loads data.

Load	P_{Dimin} (MW)	Q_{Dimax} (MVAr)	Load	P_{Dimin} (MW)	Q_{Dimax} (MVAr)
1	0	0	16	3.5	1.8
2	21.7	12.7	17	9	5.8
3	2.4	1.2	18	3.2	0.9
4	7.6	1.6	19	9.5	3.4
5	94.2	19	20	2.2	0.7
6	0	0	21	17.5	11.2
7	22.8	10.9	22	0	0
8	30	30	23	3.2	1.6
9	0	0	24	8.7	6.7
10	5.8	2	25	0	0
11	0	0	26	3.5	2.3
12	11.2	7.5	27	0	0
13	0	0	28	0	0
14	6.2	1.6	29	2.4	0.9
15	8.2	2.5	30	10.6	1.9

Table 3. Generators data.

Generator	P_{Gimin} (MW)	P_{Gimax} (MW)	Q_{Gimin} (MVAr)	Q_{Gimax} (MVAr)
1	50	200	-20	250
2	20	80	-20	100
5	15	50	-15	80
8	10	35	-15	60
11	10	30	-10	50
13	12	40	-15	60
HYDRO	0.1	4	0	0
PV	0.01	0.29	0	0
WT	0.6	2.7	0	0

Table 4. Generators cost coefficients.

Generator	a [EUR/MWh^2]	b [EUR/MWh]	c [EUR/h]
1	0.00375	2.00	0
2	0.0175	1.75	0
5	0.0625	1.00	0
8	0.0083	3.25	0
11	0.0250	3.00	0
13	0.0260	3.00	0
HYDRO	0	3.00	0
PV	0	8.00	0
WT	0	4.10	0

The total load of the IEEE 30 bus test system is 283.4 MW. The corresponding load scaling factor (LSF) is 1.0. The daily loads demand of the IEEE 30 bus test system are presented in table 5.

The data for the load demand is formulated in [6,16].

Table 5. Load scale factor data.

Hour [h]	LSF	Hour [h]	LSF	Hour [h]	LSF
1	0.90	9	1.30	17	1.50
2	0.96	10	1.15	18	1.55
3	1.00	11	1.10	19	1.40
4	1.05	12	1.05	20	1.20
5	1.10	13	1.16	21	1.12
6	1.15	14	1.30	22	1.03
7	1.30	15	1.40	23	0.96
8	1.40	16	1.45	24	0.90

The minimum load demand is 255.06 MW (0.9 LSF) between 24:00 and 1:00, while the maximum load demand is 439.27 MW (1.55 LSF) at 18:00.

4. SCADA simulation

The simulation is performed using the CitectSCADA software [17], which can be used to create applications or projects, configure dynamic graphics, create alarms and trends, and then run those projects like a real system.

The simulation will take in consideration the power demand (table 5), with the remark that only the active power is considered in this simulation. Also the power losses are not taken into account. Also, considering the advantages and disadvantages presented in section 2, a 10 MW hydrogen storage unit is chosen and inserted in the simulation system.

The SCADA simulation interface contains the following components:

- 9 generators, each with a slide bar and a numerical object (####) that illustrates the power output;
- a storage unit, with a slide bar and a numerical object (####) that illustrates the power stored or the output;
- 2 meters, which are illustrating the total generated power and the total load;
- 2 charts, which are illustrating the total generated power and the total load;
- the load (AC consumers), with a slide bar and a numerical object that illustrates the power consumption;
- a numerical object that illustrates the hour of the simulation;
- 3 buttons and 3 symbols (lights) for each DG, that are illustrating if the distributed generator is on-grid or off-grid;
- a Cicode Object (f(x)) which controls the system.

The most important is the Cicode Object (f(x)) which automatically controls the system. Cicode is a programming language, similar with "C" or Visual Basic, which controls all the system components from the graphic page, like the tags (buttons, slide bar, numerical object etc.), local variables or the graphics. In the Cicode Object the program functioning is written:

- if the DGs are off-grid then the dispatch order is presented in table 6 (left side);
- if the DGs are on-grid then the dispatch order is presented in table 6 (right side);
- if the generation is higher than the consumption, the excess power is stored;
- if the generation is lower than the consumption, the necessary power is taken from the storage unit.

The only control of the user over the system is to connect or disconnect the DGs. This is done by pressing the corresponding button of the DG from the user interface.

The simulation will take in consideration the power demand (table 5), with the remark that only the active power is considered in this simulation. Also the power losses are not taken into account. Also, considering the advantages and disadvantages presented in section 2, a 10 MW hydrogen storage unit is chosen and inserted in the simulation system.

The distributed generators power output is presented in Fig. 1, while the daily load demands of the IEEE 30 bus test system and maximum generation output is presented in Fig. 2.

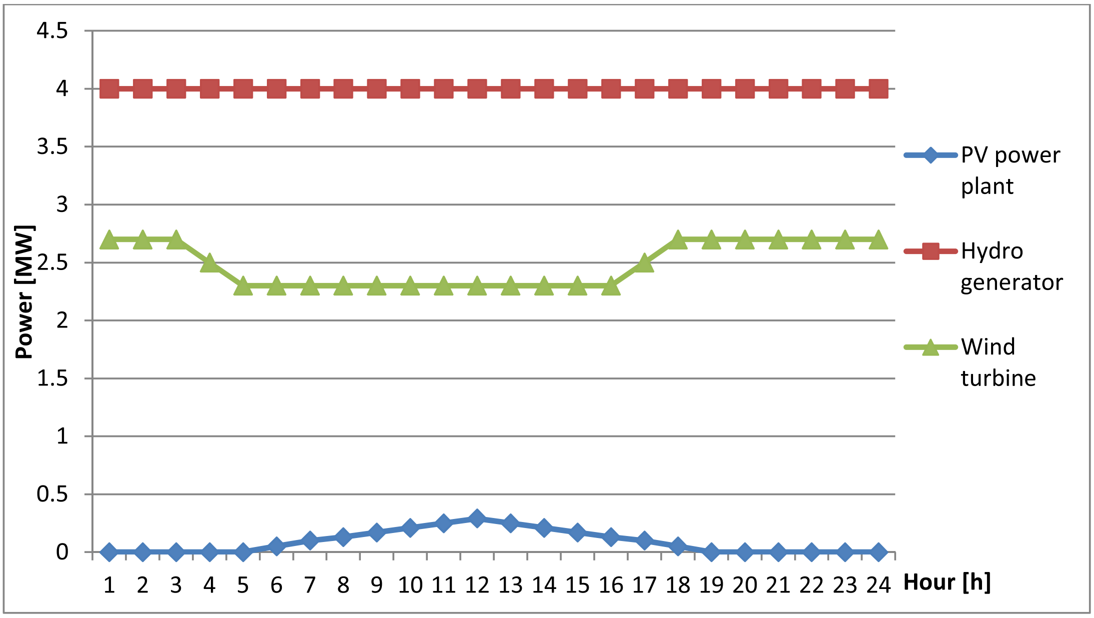

Fig. 1. Distributed generators power output

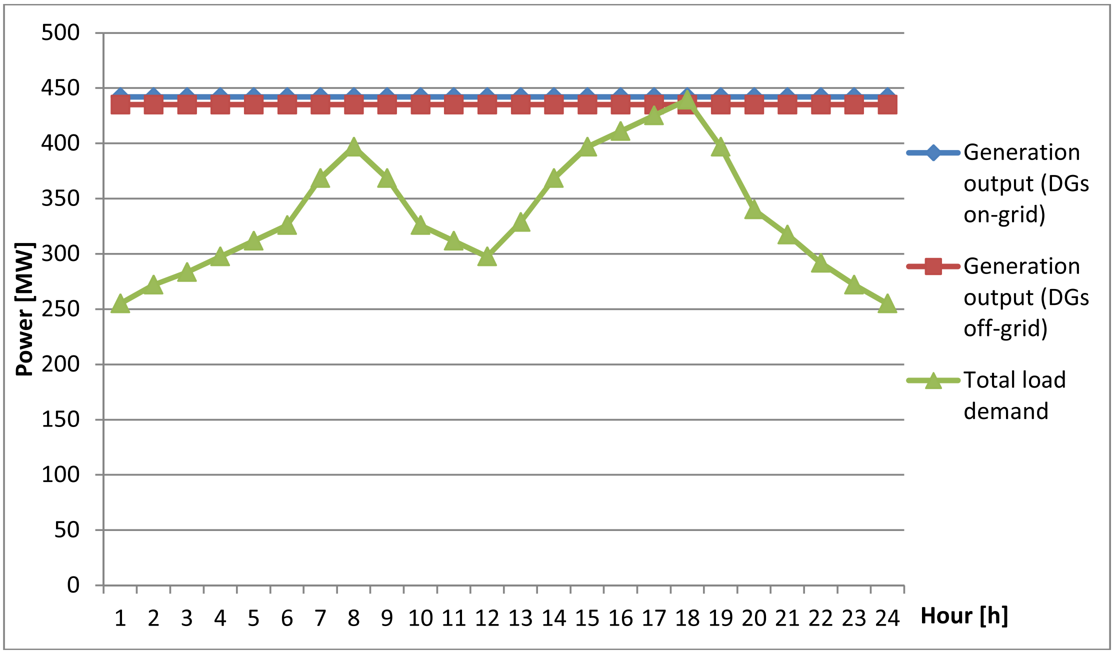

Fig. 2. Total load demand and generators output

The graphic in Fig. 2 highlights that the maximum load demand is 439.27 MW (1.55 LSF) at 18:00, and can be covered only if the distributed generators are on-grid. This problem has two solutions: disconnect several loads or install a storage unit. The second solution is chosen and presented further.

The system's generating units cover demand in order of their generating cost coefficient (b), with the observation that G1 is used as a reserve generator, if the other generators can't cover the load. In the first case (DGs off-grid), the order is presented in table 6 (left side). In the second case (DGs on-grid), the order is presented in table 6 (right side). In the second case the DGs have priority access to the system because the power provided by them is variable in time due to the availability of their primary source.

The simulation takes in consideration if the generated power covers the load. If it does, then the excess power is exported. If the load is higher than the generated power, then the remaining required power is supplied the first generator (generator 1) or the 10 MW hydrogen storage unit.

Table 6. Generators order in the system.

Generators order (DGs off-grid)	b [EUR/MWh]	Generator order (DGs on-grid)	b [EUR/MWh]
5	1	HYDRO	3
2	1.75	WT	4.1
HYDRO	3	PV	8
11	3	5	1
13	3	2	1.75
8	3.25	11	3
WT	4.1	13	3
PV	8	8	3.25
1	2	1	2

The SCADA simulation diagram, that synthesizes the system functioning previously described, is presented in Fig. 3.

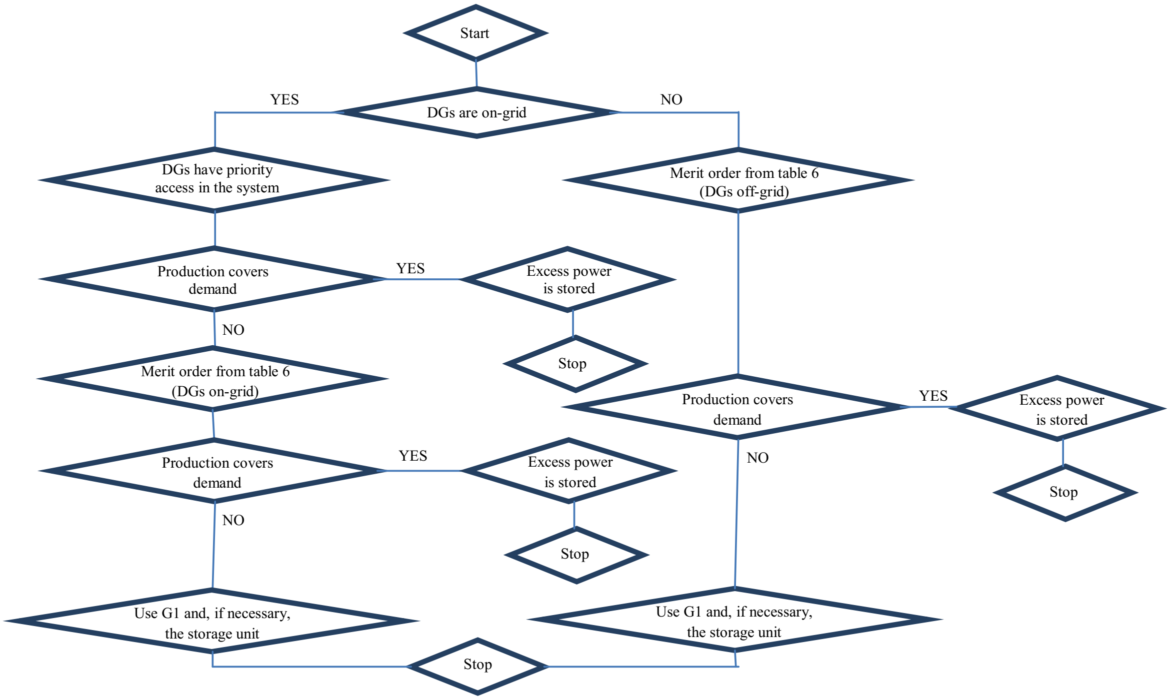

Fig. 3. SCADA simulation diagram

The simulation emphasizes that the distributed generators can't cover the load alone. At the lowest LSF, if the WT and the hydro generator are on-grid, the power produced is not enough to cover the load. In order to cover the load G5, G2, G11, G13, G8 and a part of G1 (13.36 MW) must be used. At the highest LSF, if all DGs are on-grid, the power produced is not enough to cover the load. In order to cover the load G5, G2, G11, G13, G8 and G1 (197.5 MW) must be used. If the DGs are off-grid, then the power produced is lower than the consumption (435< 439.27 MW), therefore the storage unit must be used. This is the only case when the load can't be covered without the help of the DGs or the storage unit. This emphasizes the DGs and the storage unit help cover the peak load.

5. Conclusions

Storage technologies improve the stability, reliability and quality problems caused by the power fluctuations of the DG sources, although they are not yet mature and still under development. A disadvantage is the high cost of these technologies.

The SCADA simulation emphasized that the generation output of the DG sources is too small to cover the total load alone, so the other generators were necessary to be used. When the generation output was higher than the demand, the excess power was stored. Also, when the generation output was lower than the demand, the remaining power needed was supplied by the storage unit.

In order to cover the total load, all the systems generators were used, including the reserve generator. The power supplied by the reserve generator depended on the LSF. If the LSF was low, the reserve generator supplied a limited amount of power. If the LSF was high, the reserve generator supplied a high amount of power. As a particular case, at the highest LSF, if the DGs were off-grid the generation output was lower than the demand. So, in order to prevent a blackout, the storage unit provided the necessary power. This emphasizes that the storage technologies help cover the peak load, especially when the DG sources are off-grid.

As a future study, the simulation can take in consideration the power losses. This will result in a higher use of the reserve generator and possibly the need of more storage units or a storage unit with a greater power. Also, the loads can be represented separately, so the DGs can be used to cover the power consumption at their installation point.

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